Measurements of Polarization of Heavy Mesons at CDF

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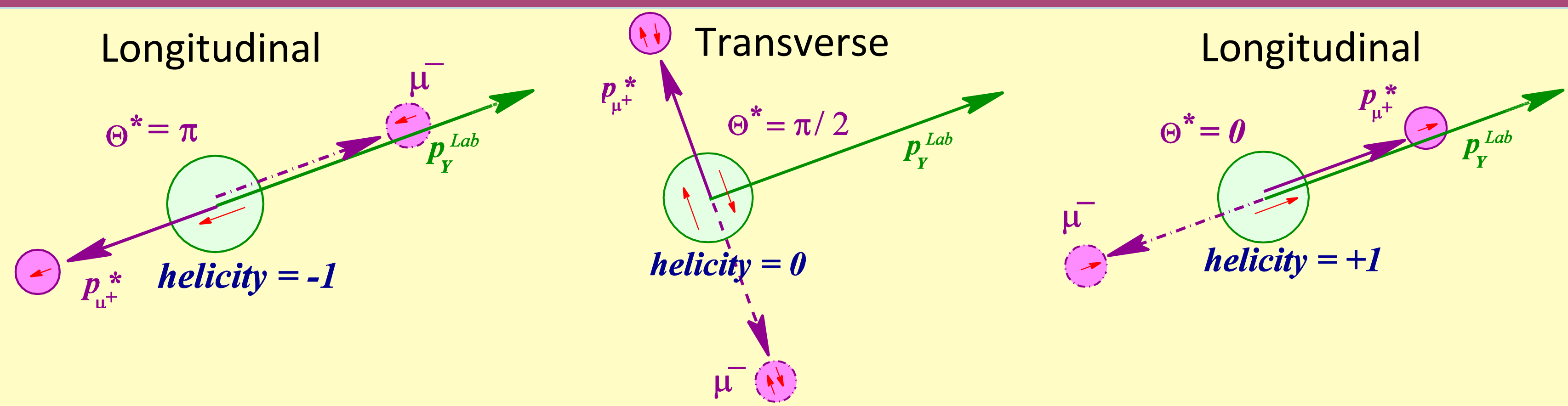
Outline

- Polarization
- Motivation
  - Background of theory and experimental results
- Measurement method
- CDF Run II Results
- Comparison of results
- Summary and Outlook

Polarization (Υ(1S) → μμ):

- Polarization is determined by measuring the angular distribution $\cos^2\theta^*$: $$dN/d(\cos\theta^*) \propto 1 + \alpha \cos^2\theta^*$$
  where α is the polarization parameter
  - Polarization is fully transverse : α=1
  - Polarization is fully longitudinal: α=-1

  and θ^* is defined as the angle between μ^+ direction in Υ rest-frame and Υ direction in lab frame



Diagrams of polarization angles with three different helicity states. When helicity states are equally populated, the vector mesons have zero polarization.

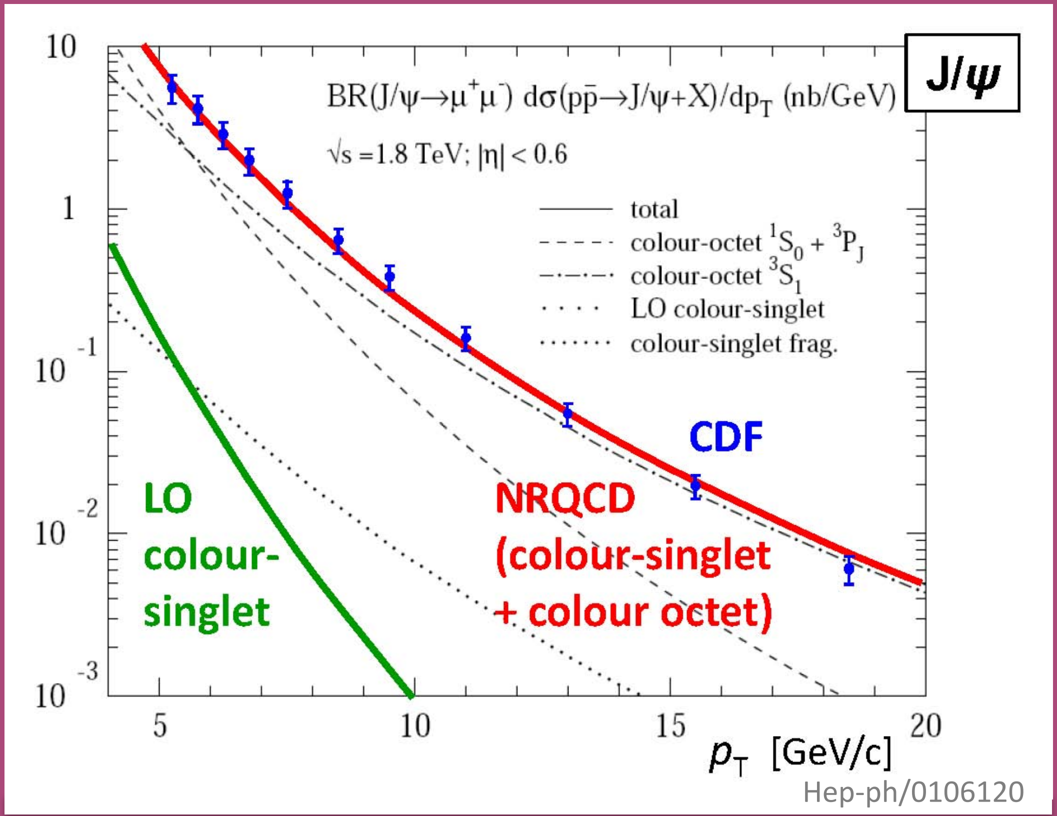
This s-channel helicity frame is used at high p_T collider experiments.

Motivation and Background

- Quarkonium production has not been explained adequately by QCD model
- Naively expect vector-meson production suppressed
  - Color Singlet Model
  - Require 3 hard gluons for colorless state (like OZI suppression)
- CDF Run I found enhanced prompt J/ψ and ψ' production
- $\sigma(\psi')$ is **50x** LO expectation
- Feed-down from χ states should dominate J/ψ prompt production
  - Two-gluon production
- CDF Run I reported that $\sim 30\%$ of prompt J/ψ came from χ states

Enter NRQCD Theory

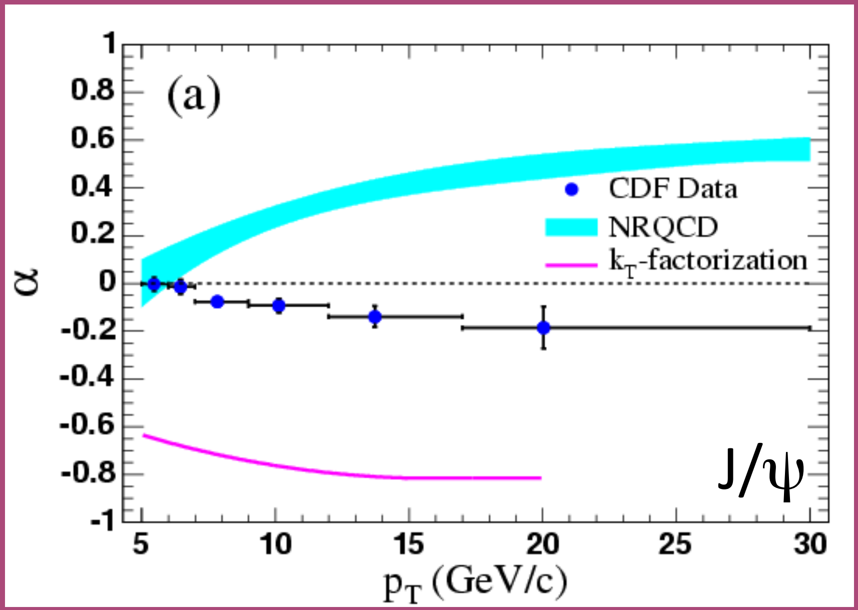
- Non-Relativistic QCD introduces color octet model
- Can largely fit J/ψ and ϒ(1S) production spectra



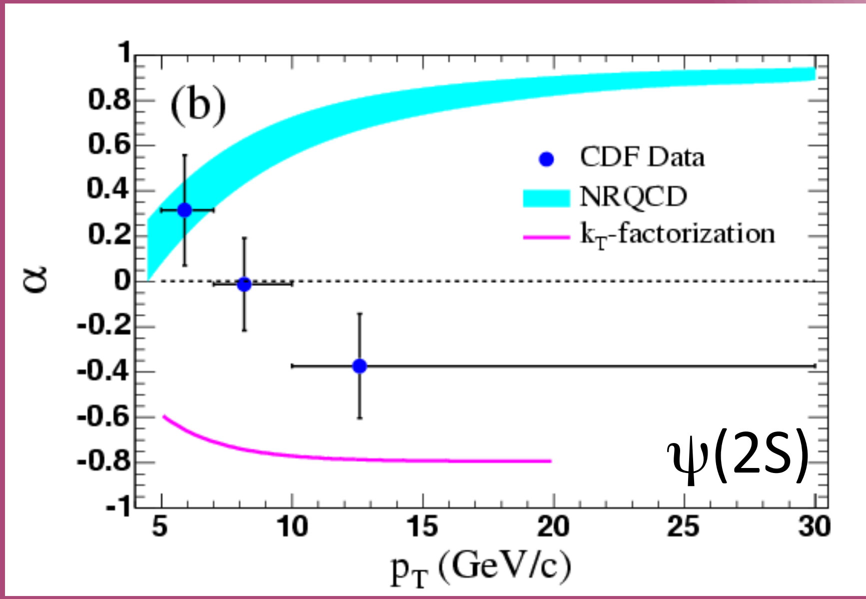
Production spectrum looks good!
How well does NRQCD predict charmonium polarization?

- Predict strong transverse polarization at high momentum ($p_T^2/M^2 >> 1$)
  - Meson carries properties of the hard gluon parent

Charmonium Polarization

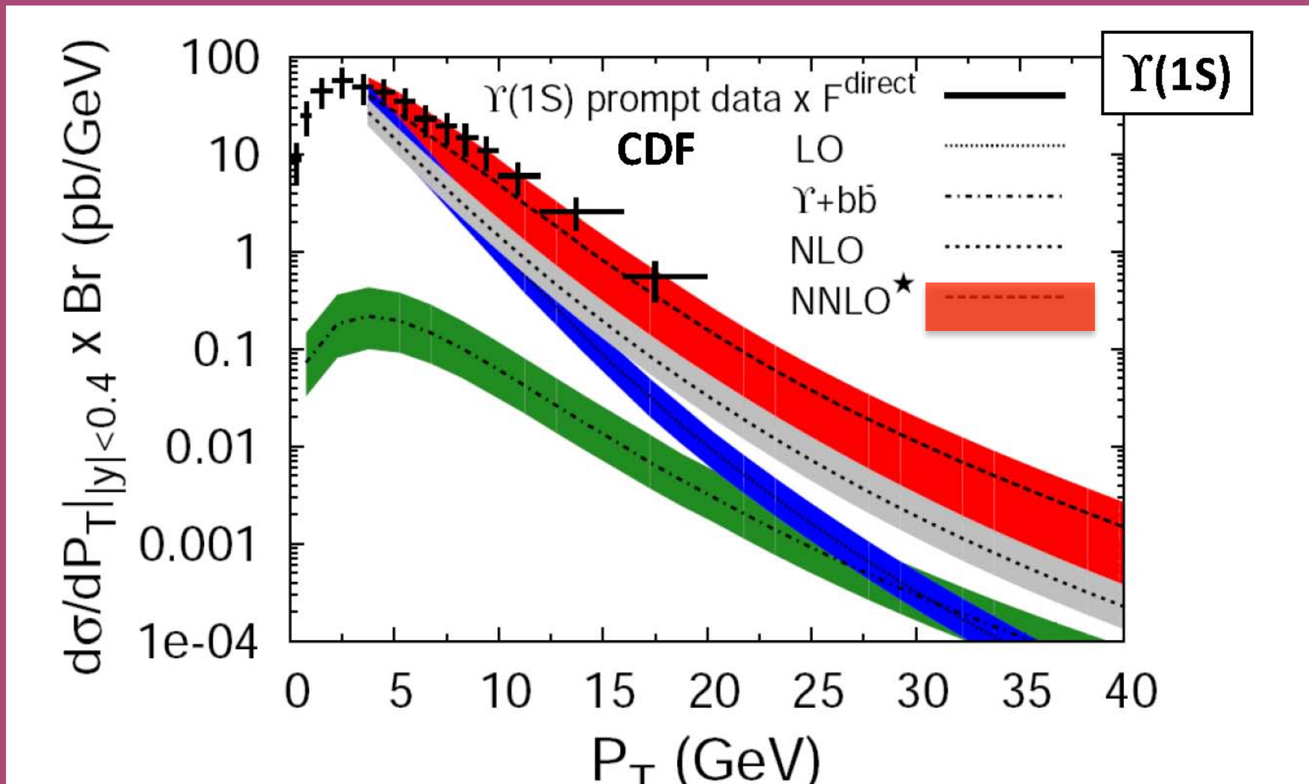


$$dN/d(\cos\theta^*) \propto 1 + \alpha \cos^2\theta^*$$



- Inconsistent with NRQCD
  - Question: is the charm quark "heavy"?
    - The bottom quark is!
- Newer NNLO* models predict longitudinal Υ polarization

NNLO* Can Explain Υ(1s) Production



Phys. Rev. Lett. 101, 152001

- Predicting production spectra not a sufficient test of models
  - Need polarization, too.
  - NNLO* model predicts longitudinal Υ(1s) polarization at high p_T

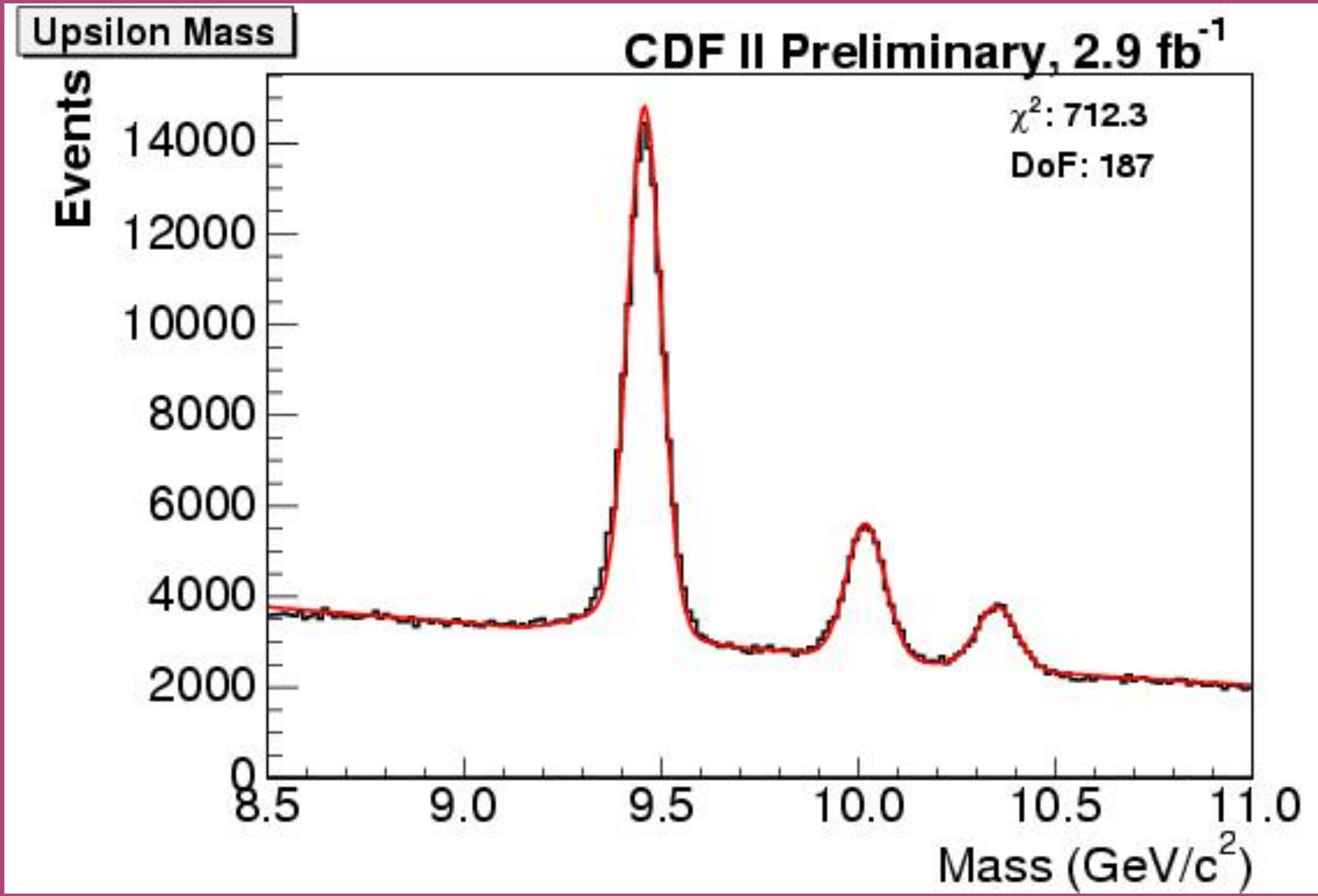
Measurement Method

$$dN/d(\cos\theta^*) \propto 1 + \alpha \cos^2\theta^*$$

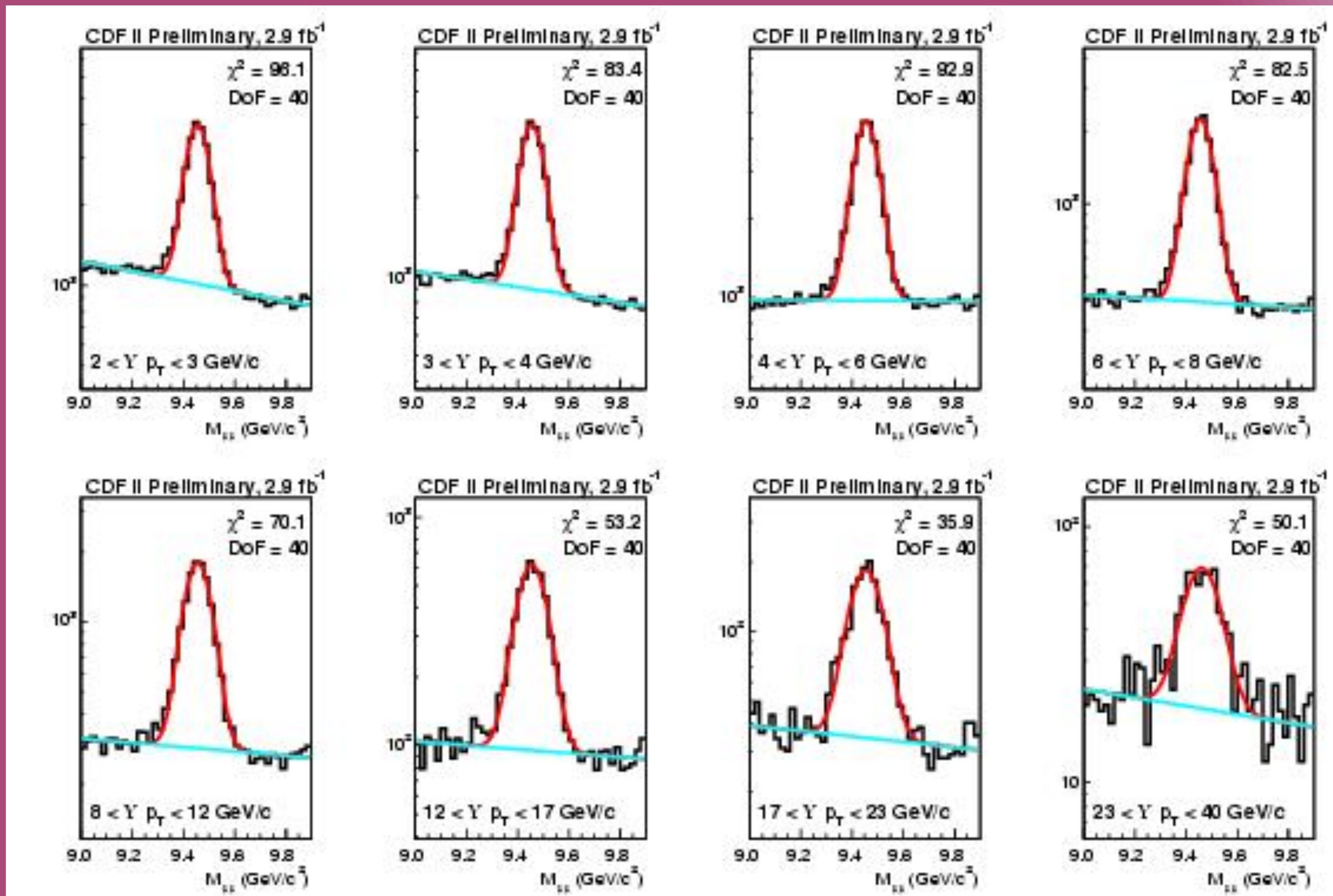
- Measure $\Upsilon \rightarrow \mu\mu$ yield in bins of p_T and $\cos\theta^*$
- Correct for apparatus acceptance and trigger conditions that affect angular distribution
  - Use MC samples generated with fully transverse (α=1) and fully longitudinal (α=-1) polarizations as templates
  - These templates are weighted to find the proper admixture of polarization that agrees with the data
- Proper treatment of background is crucial
  - Use sideband angular distribution to isolate signal angular distribution
  - Make simultaneous fit to polarization parameter and background in $\cos\theta^*$ bins

$\Upsilon \to \mu^+\mu^-$ Mass Distribution

- 2.9 fb^{-1}
- 83,000 Υ(1S) candidates
- |y|<0.6
- Resolve 3 peaks

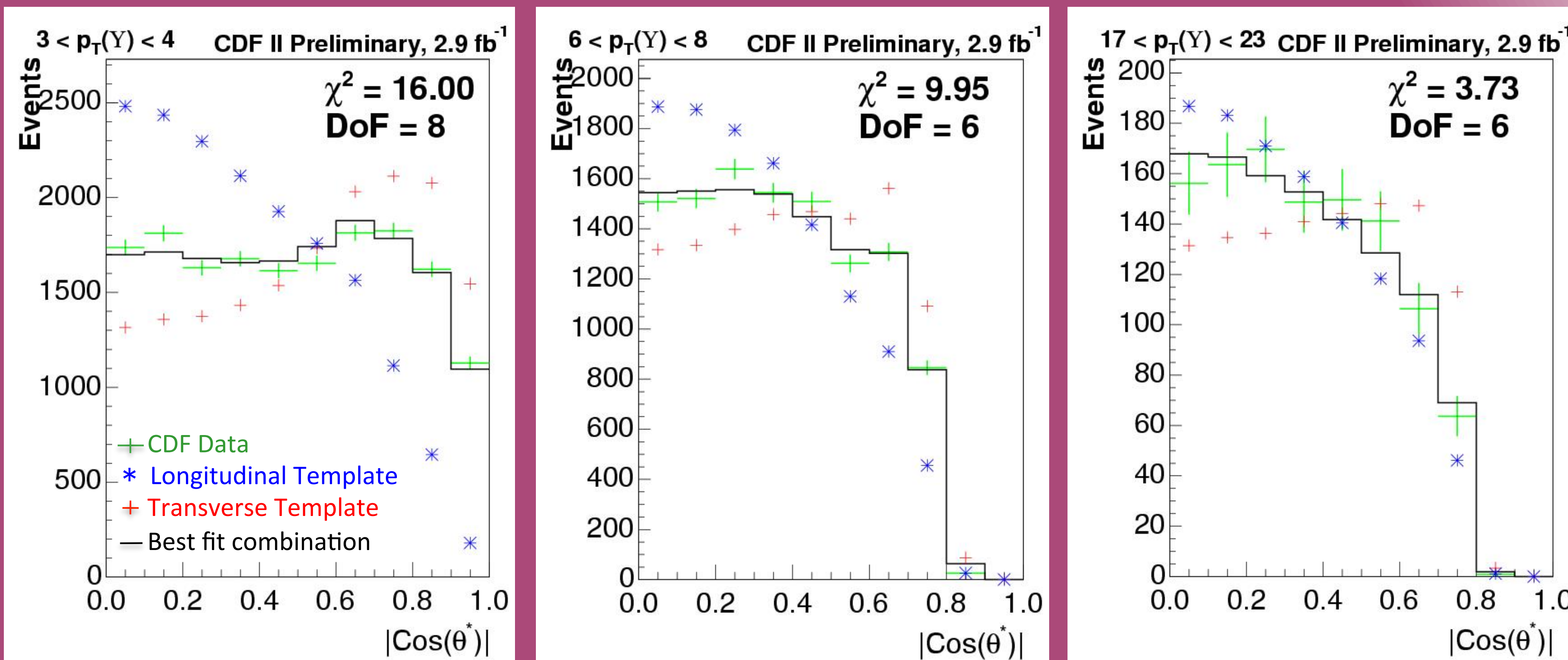


$\Upsilon(1S) \rightarrow \mu^+\mu^-$ Mass Fits in p_T bins



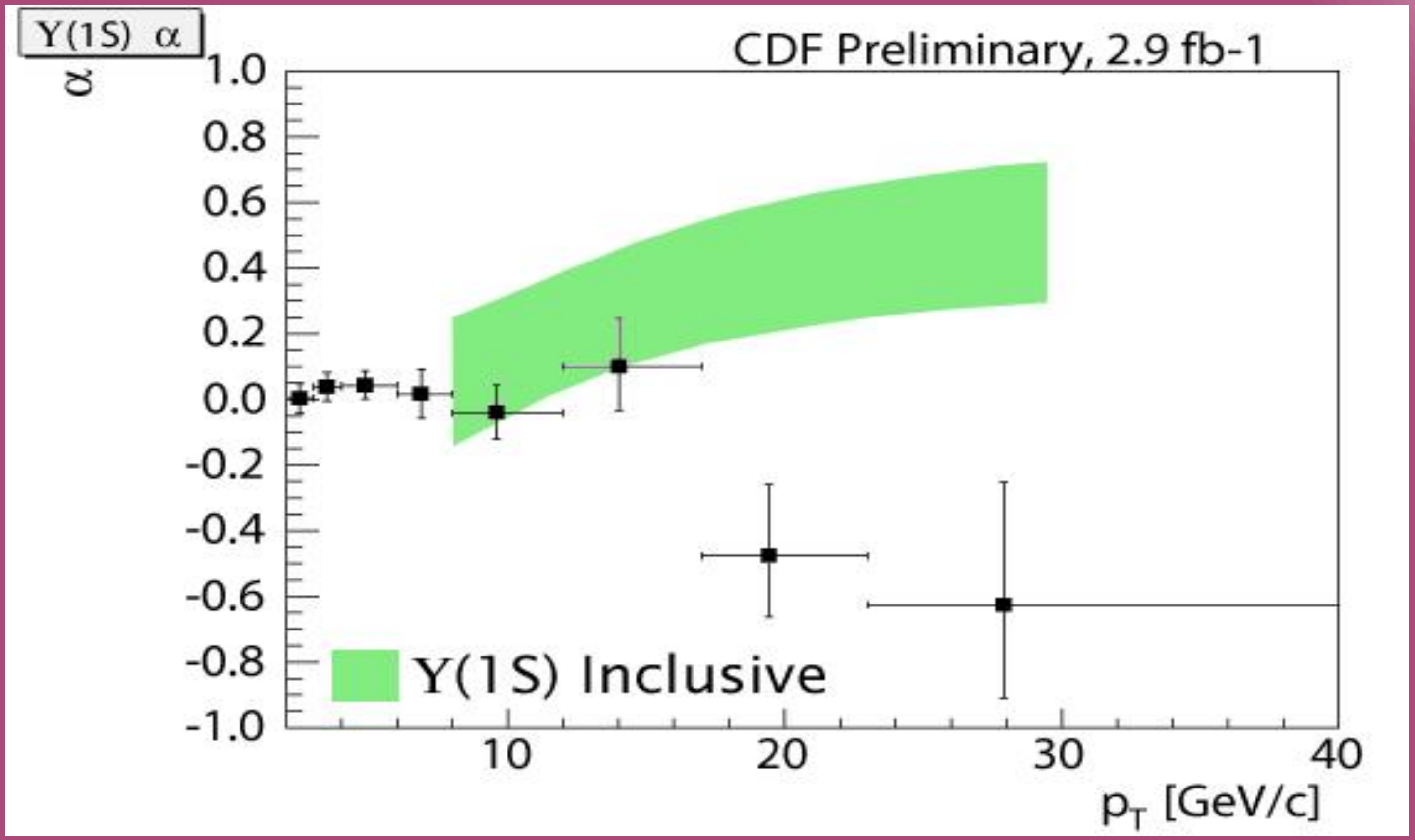
- Fits in p_T bins
  - Shape used when subdividing into $\cos\theta^*$ bins

Cosθ* Distributions and Template Fits



- High p_T bin is most sensitive to differences between models
  - Suffers from acceptance limits

Results



– Υ(1S) prompt polarization, including feed-down from χ_b, Υ(nS)
– Green band is NRQCD prediction including feeddown (PRD 63, 071502 (2000))

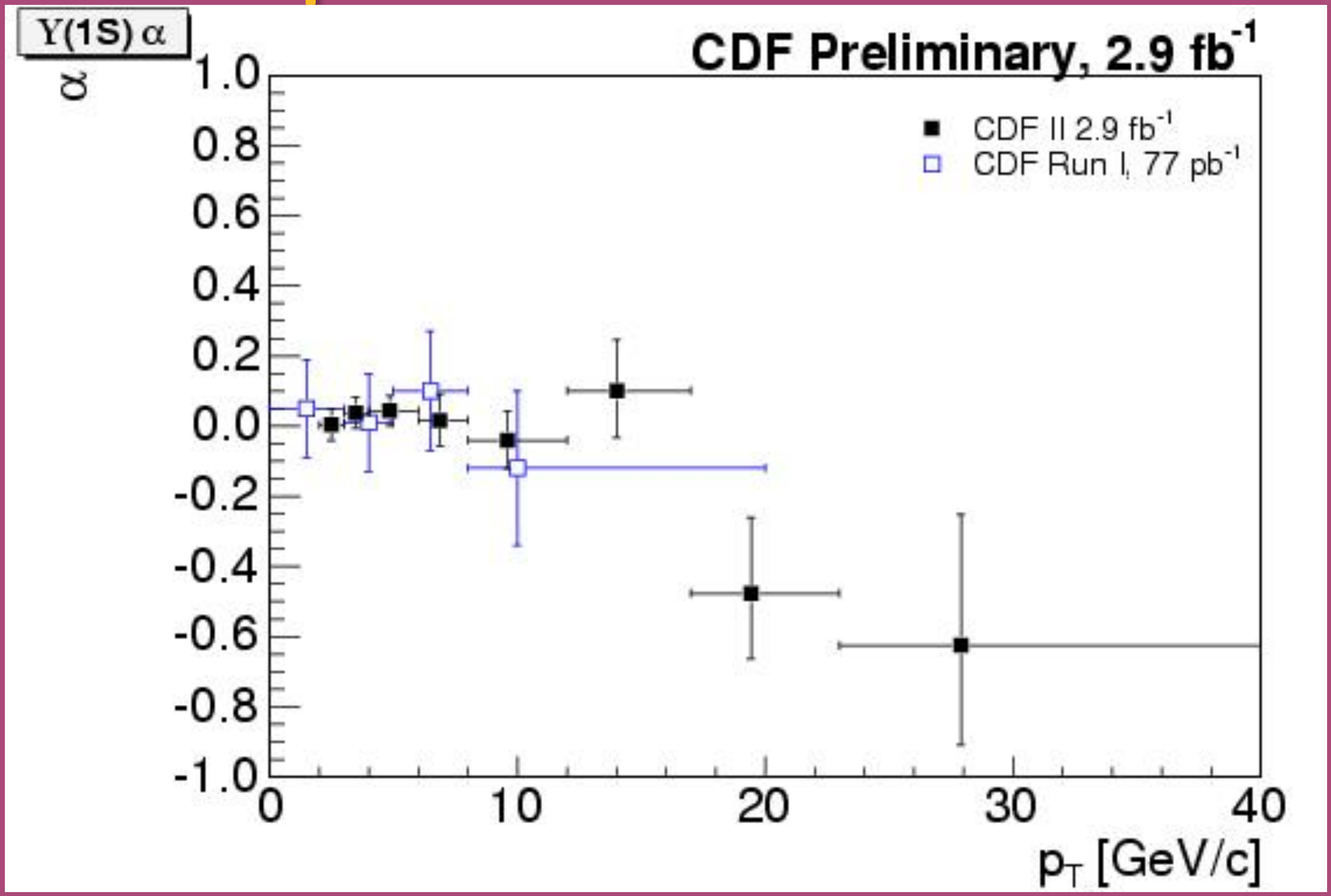
Systematic Uncertainties

- Dominated by
  - Fitting/counting technique
  - Trigger efficiency turn-on
- Small

$\Upsilon(1S)$ Polarization			
$p_T(\Upsilon)[GeV/c]$	Data Yield	Background	η
2-3	17316 ± 294	11147 ± 172	$0.332 \pm 0.020(stat) \pm 0.003(syst)$
3-4	16819 ± 283	9819 ± 161	$0.317 \pm 0.019(stat) \pm 0.003(syst)$
4-6	22012 ± 312	10636 ± 168	$0.315 \pm 0.019(stat) \pm 0.003(syst)$
6-8	11291 ± 217	4300 ± 107	$0.326 \pm 0.032(stat) \pm 0.003(syst)$
8-12	9846 ± 197	3104 ± 91	$0.351 \pm 0.038(stat) \pm 0.003(syst)$
12-17	3740 ± 117	1035 ± 53	$0.290 \pm 0.058(stat) \pm 0.003(syst)$
17-23	1182 ± 71	372 ± 32	$0.586 \pm 0.126(stat) \pm 0.003(syst)$
23-40	430 ± 47	208 ± 23	$0.685 \pm 0.229(stat) \pm 0.003(syst)$

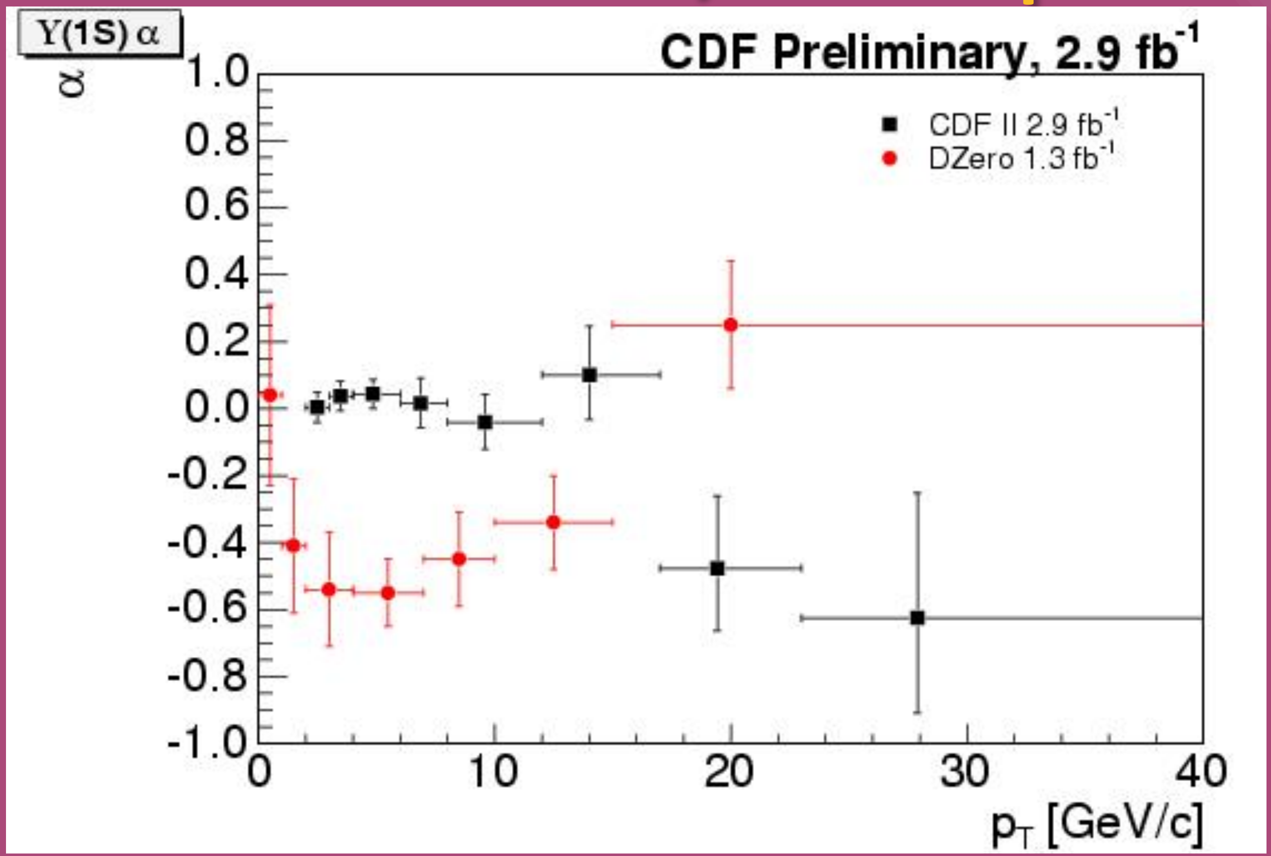
Note: η is a fitting parameter defined as $\eta \equiv \frac{\sigma_L}{\sigma_T + \sigma_L} = \frac{1-\alpha}{3+\alpha}$

Results: CDF Run II and Run I Comparison



- Polarization is small for $p_T < 20$ GeV
- Run II data show trend to longitudinal polarization at high p_T

Results: CDF and DØ Comparison



- CDF and DØ results largely inconsistent
  - Use similar techniques
  - Different rapidity regions
    - CDF: |y|<0.6   DØ: |y|<1.8

Summary and Outlook

- Vector meson polarization measurements are vital to understanding NRQCD and other production models
- CDF has measured the Υ(1S) polarization using 2.9/fb of data
  - Measurement showed trend toward longitudinal polarization with increasing p_T
  - CDF Run I and Run II results are consistent
  - CDF and D0 Run II results show different trends
- Experimental and theoretical puzzles still need to be understood

- Extending analyses at CDF
  - Include Υ(2S) and Υ(3S)
  - Increase data sample